SCHOOL OF CIVIL ENGINEERING

INDIANA DEPARTMENT OF HIGHWAYS

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-86/18

Implementation Report (2)

STABL6 WITH REINFORCING LAYER OPTION -- USER'S MANUAL --

D. N. Humphrey
R. D. Holtz

PURDUE UNIVERSITY

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-86/18

Implementation Report (2)

STABL6 WITH REINFORCING LAYER OPTION -- USER'S MANUAL --

D. N. Humphrey
R. D. Holtz

Implementation Report (2)

STABL6 WITH REINFORCING LAYER OPTION
-- USER'S MANUAL --

TO:	H. L. Michael, Director Joint Highway Research Project	DATE:	October 14, 1986
		PROJECT:	C-36-36Q
FROM:	R. D. Holtz, Research Engineer Joint Highway Research Project	FILE:	6-14-17

Attached is a user's manual on the HPR Part II research study entitled "Design of Reinforced Embankments." This report, a user's manual, is the implementation part of Task 5 of the approved work plan. The authors of the report are Mr. D. N. Humphrey and myself.

The popular stability analysis program STABL, which can be used to analyze ordinary unreinforced embankments on soft foundations, was modified so that reinforced embankments also could be considered. The new program, termed STABL6, uses the simplified Bishop's analysis method, and it is implemented on IBM PC-compatible micro computers. The User's Manual gives detailed input instructions as well as an example problem which illustrates the analysis of a typical reinforced highway embankment. The report should be useful to highway designers who wish to utilize simple limiting equilibrium analysis methods for design pruposes.

Copies of the report will be submitted to the IDOH and FHWA for their reveiw. I look forward to receiving their comments on the manual.

Sincerely yours,

R. D. Holtz, Ph.D., P.E.
Research Engineer

RDH/kr
Attachment

cc:	A. G. Altschaeffl	D. E. Hancher	P. L. Owens
	J. M. Bell	R. A. Howden	B. K. Partridge
	M. E. Cantrall	M. K. Hunter	G. T. Satterly
	W. F. Chen	J. P. Isenbarger	C. R. Scholer
	W. L. Dolch	J. F. McLaughlin	K. C. Sinha
	R. L. Eskew	K. M. Mellinger	C. A. Venable
	J. D. Fricker	R. D. Miles	T. D. White
			L. E. Wood

IMPLEMENTATION REPORT (2)

STABL6 WITH REINFORCING LAYER OPTION
-- USER'S MANUAL --

by

D. N. Humphrey
Graduate Instructor in
Research

and

R. D. Holtz
Research Engineer

Joint Highway Research Project

Project No.: C-36-36Q

File No.: 6-14-17

Prepared as Part of an Investigation

Conducted by

Joint Highway Research Project
Engineering Experiment Station
Purdue University

in cooperation with the

Indiana Department of Highways

Purdue University
West Lafayette, Indiana
October 14, 1986

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IN/JHRP-86/18		

4. Title and Subtitle	5. Report Date
STABL6 WITH REINFORCING LAYER OPTION -- USER'S MANUAL	October 14, 1986
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
D. N. Humphrey and R. D. Holtz	JHRP-86-18
9. Performing Organization Name and Address	10. Work Unit No.
Joint Highway Research Project Civil Engineering Building Purdue University West Lafayette, IN 47907	11. Contract or Grant No. HPR-1(24) Part II
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Indiana Department of Highways State Office Building 100 North Senate Avenue Indianapolis, IN 46204	Implementation Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration. Study entitlted "Design of Reinforced Embankments."

16. Abstract

The capability to analyze reinforced embankments has been incorporated into the STABL slope stability analysis program. The new program is called STABL6. This user's manual describes how the simplified Bishop's method was modified to include reinforcing layers. The modified program can analyze multiple reinforcing layers and allows the orientation of the reinforcing force to be specified. Input instructions and an example problem for the reinforcing layer option are given.

17. Key Words	18. Distribution Statement
Stability analysis, reinforcement, embankments, design, analysis, limiting equilibrium	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
unclassified	unclassified	33	

Form DOT F 1700.7 (8-69)

TABLE OF CONTENTS

	Page
HIGHLIGHT SUMMARY	v
INTRODUCTION	1
ANALYSIS OF EMBANKMENTS WITH REINFORCING LAYERS USING SIMPLIFIED BISHOPS METHOD	2
Background	2
Implementation	6
SUMMARY	10
ACKNOWLEDGEMENTS	10
APPENDIX A - REFERENCES	10
APPENDIX B - EXAMPLE PROBLEM	12
APPENDIX C - DATA INPUT FORMAT FOR REINFORCING LAYERS	19
APPENDIX D - REINF ERROR CODES	21
APPENDIX E - MODIFICATIONS TO PC-STABL5	22
APPENDIX F - LIST OF ADDITIONS AND MODIFICATIONS TO PLOTSTBL.BAS	33

HIGHLIGHT SUMMARY

The capability to analyze reinforced embankments has been incorporated into the STABL slope stability analysis program. The new program is called STABL6. This user's manual describes how simplified Bishop's method was modified to include reinforcing layers. The modified program can analyze multiple reinforcing layers and allows the orientation of the reinforcing force to be specified. Input instructions and an example problem for the reinforcing layer option are given.

PC-STABL6 WITH REINFORCING LAYER OPTION
-- USER'S MANUAL --

INTRODUCTION

A slope stability program PC-STABL5 developed at Purdue University was modified to give it the capability to analyze embankments constructed on soft ground reinforced with one or more layers of reinforcement. This modified program is called PC-STABL6. It was developed as part of a study of design of reinforced embankments (Humphrey and Holtz, 1986a) that also included a finite element analysis procedure (Humphrey and Holtz, 1986b). PC-STABL5 is a general purpose limiting equilibrium slope stability analysis program with solution options that use the simplified Janbu method with circular, sliding block, or irregular shaped sliding surfaces or the simplified Bishop or Spencer methods with circular surfaces. Program operation is described in Siegel (1975a), Lovell, et al. (1984), and Carpenter (1985). Further details on program development are given in Siegel (1975b) and Boutrup (1978). The program is written in FORTRAN77 and operates on IBM-PC, IBM-XT, IBM-AT, or compatible computers.

The simplified Bishop analysis routine was modified to include the stabilizing moment provided by one or more

layers of reinforcement. The user inputs the location of each layer, the distribution of available force, and the direction in which the force acts. The circular trial surface may be specified or PC-STABL5's surface generation routine may be used.

This report is a user's manual for analysis of reinforced embankments with PC-STABL6. Only aspects of the program specific to the reinforcement option are covered. The user is referred to the references noted above for general instructions on program use. In the following, the method used to incorporate the stabilizing effect of the reinforcing layer is described and an outline of the solution procedure is given. Appendix A lists references cited. Appendix B gives an example problem. The data input format is detailed in Appendix C. Error codes used by the reinforcing layer routines are given in Appendix D. Appendix E lists the modifications made to PC-STABL5 and two new subroutines that were added. Modifications to the routine to output problem geometry on a Hewlett-Packard 7470A two pen plotter are listed in Appendix F.

ANALYSIS OF REINFORCING LAYERS WITH SIMPLIFIED BISHOPS METHOD

Background

Tensile reinforcing layers provide a resisting moment which increases embankment stability. This effect was

incorporated into the simplified Bishop (1955) method of analysis. It was assumed that the reinforcement provides only a resisting moment and does not alter the stresses on the assumed slip surface. Finite element analyses confirmed that the reinforcement has an insignificant effect on normal stresses on the portion of the failure surface passing through the embankment (Humphrey and Holtz, 1986a). Furthermore, the soil strength and available reinforcing force are assumed to be mobilized simultaneously. The implications of this assumption should be critically examined when the foundation soils reach a peak shear strength at small strain followed by strain softening.

In the simplified Bishop method a circular shaped slip surface is assumed and divided into a number of slices. A slip surface and the forces acting on a typical slice are shown in Fig. 1. The reinforcing force F_R acting at the intersection of the slip surface and the reinforcement is also shown. F_R has units of force/unit width. It provides a resisting moment equal to F_R times its moment arm, y, about the center of the circle. If there are multiple reinforcing layers, the total resisting moment is the sum of the resisting moment provided by each layer. This additional resisting moment is included in the equation for the safety factor (Ingold, 1982; Humphrey and Holtz, 1986):

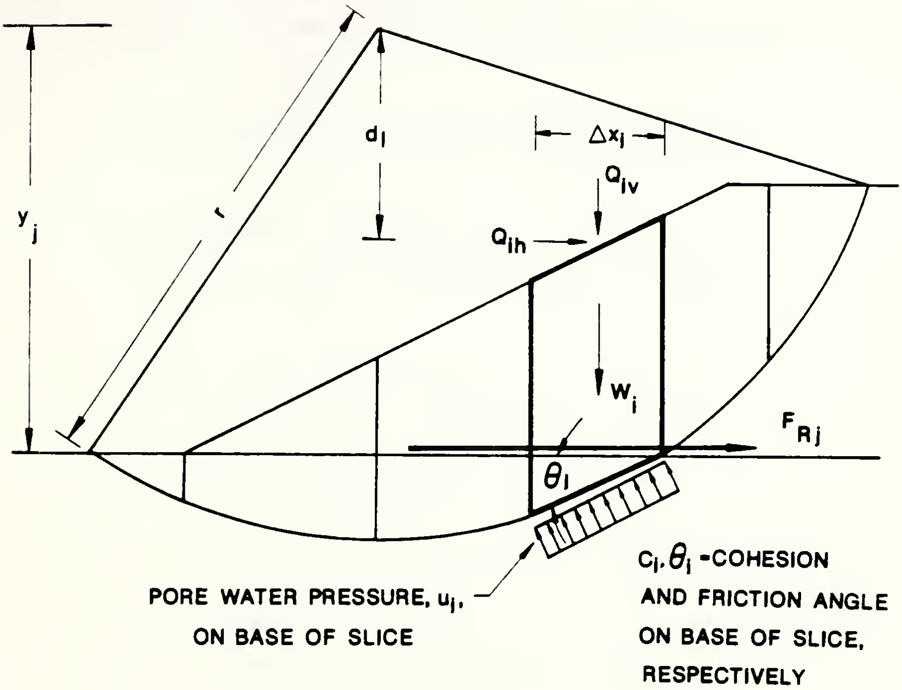


Figure 1 Simplified Bishop method of slices including horizontal reinforcing force showing forces acting on i^{th} slice.

$$SF = \frac{\sum_{i=1}^{n} \left[\frac{c_i \Delta x_i + [W_i + Q_{iv} - u_i \Delta x_i] \tan\phi_i}{\cos\theta_i + (\sin\theta_i \tan\phi_i)/SF} \right]}{\sum_{i=1}^{n} (W_i + Q_{iv}) \sin\theta_i - [\sum_{i=1}^{n} Q_{ih} d_i]/r - (\sum_{j=1}^{m} F_{Rj} y_j)/(rSF)} \quad (1)$$

where: W_i = weight of the i^{th} slice

Q_{iv} = vertical surface load applied to the i^{th} slice

Q_{ih} = horizontal surface load applied to the i^{th} slice

d_i = moment arm of Q_{ih}

u_i = pore water pressure acting on base of i^{th} slice

Δx_i = width of i^{th} slice

θ_i = inclination of base of i^{th} slice

c_i = cohesion on base of i^{th} slice

ϕ_i = friction angle on base of i^{th} slice

r = radius of assumed trial circle

n = number of slices

F_{Rj} = force in j^{th} reinforcing layer

y_j = moment arm for j^{th} reinforcing layer

m = number of reinforcing layers

SF = safety factor

The safety factor which satisfies Eq. 1 is found by trial and error. This equation was implemented in STABL5.

Implementation

To use the reinforcing option, the location of each layer is specified by a series of x,y coordinates starting at the left end of the reinforcement and moving to the right as shown in Fig. 2. In a typical application the left end of the layer would be at the embankment toe or the face of the slope and would extend across the full width of the embankment. The layer may be horizontal or inclined, however, the user must employ judgment on the applicability of the analysis method if the layers are more than moderately inclined. It is the user's responsibility to define a reasonable reinforcement geometry.

The available force and orientation of the force is specified at each point defining the reinforcing layer. Similar procedures were used by Duncan, et al. (1985). Suggestions on choice of the available force and its orientation are given in Humphrey and Holtz (1986a). The orientation of the force is specified by the inclination factor I_f. I_f varies from 0.0 which specifies that the force acts in the direction of the reinforcement to 1.0 which specifies that it acts tangent to the slip surface as shown in Fig. 3.

The right most intersection of each reinforcing layer and the trial surface is located. Then the force (F_{Rj}) and inclination factor (I_{fj}) at the intersection is found by linear interpolation between the adjacent specified points (Fig. 2). It is possible for the toe of some trial circles

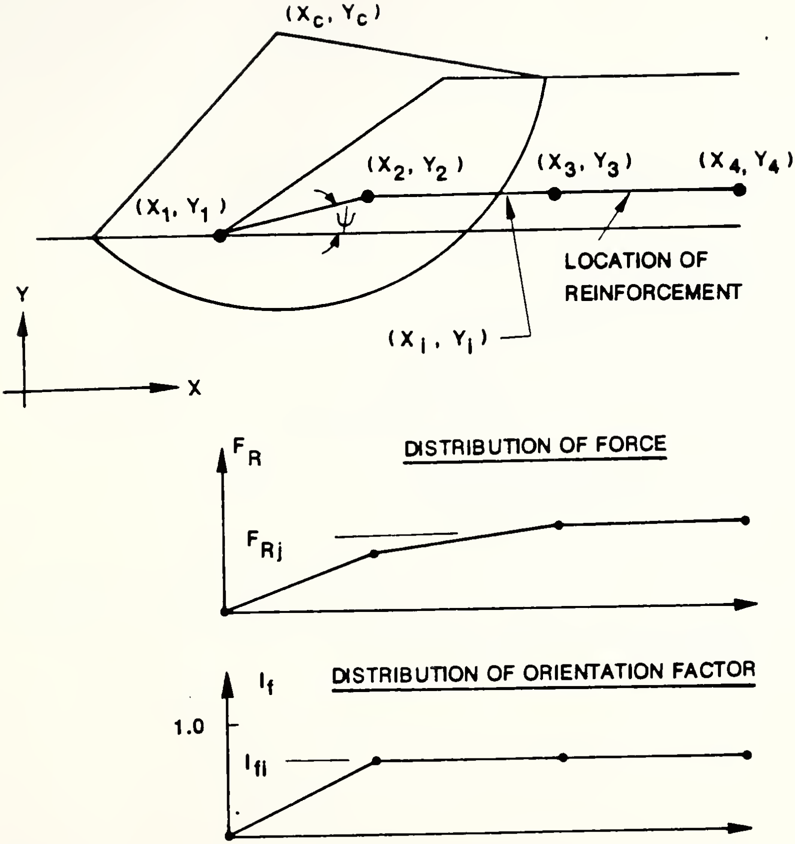


Figure 2 Location of reinforcement and distribution of force and inclination factor.

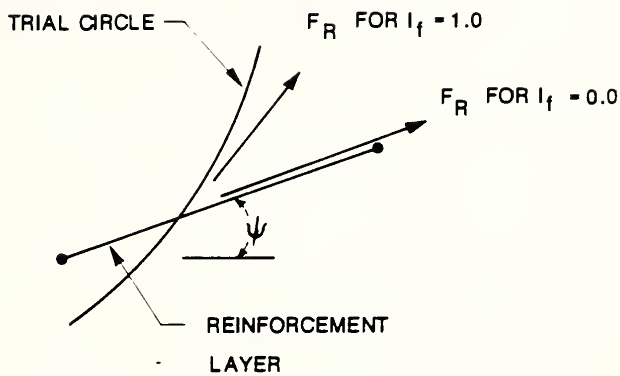


Figure 3 Orientation of reinforcement force.

to intersect a layer a second time but this is assumed to have no effect on stability.

The moment arm (y) is a function of the trial circle radius (r), the slope of the reinforcement (ψ), the inclination factor, the coordinates of the circle center (x_c, y_c), and the coordinates of the intersection (x_i, y_i) as shown on Fig. 2. For a horizontal layer and $I_f = 0.0$, $y = y_c - y_i$ and for $I_f = 1.0$, $y = r$. For other cases

$$A = \text{atan}[(x_c - x_i)/(y_c - y_i)] \tag{2}$$

$$y = r \sin[\pi/2 - A + \psi + I_f(A - \psi)] \tag{3}$$

The reinforcing option is implemented only for the simplified Bishop method. This restricts solution options to SURBIS for a single specified trial circle or CIRCL2 for multiple circles generated using a random technique. An example problem using the SURBIS option is shown in Appendix B. Input instructions are given in Appendix C and error codes are listed in Appendix D.

STABL5 has the capability to analyze many different types of problems. Some combinations of solution options may produce unrealistic results, for example, using the reinforcing and tieback options together. The user should exercise good judgment in this regard.

SUMMARY

A modification to a general purpose slope stability program STABL5 is described which gives it the capability to analyze reinforced embankments constructed on soft ground. The modification is based on the simplified Bishop method of slices. Multiple reinforcing layers with specified distributions of available force may be used. The equations and procedures used in the implementation are given. An example problem, input instructions, error codes, and modifications to STABL5 are given in the appendices.

ACKNOWLEDGEMENTS

Financial support for this research was provided by the Indiana Department of Highways and the Federal Highway Administration through the Joint Highway Research Project of Purdue University. This support is gratefully acknowledged.

APPENDIX A - REFERENCES

Bishop, A. W. (1955), "The use of the slip circle in the stability analysis of slopes," Geotechnique, Vol. 5, No. 1, pp. 7-17.

Boutrup, E. (1978), "Computerized slope stability analysis for Indiana Highways," Masters Thesis, School of Civil Engineering, Purdue University, West Lafayette, Indiana 47907.

Carpenter, J. R. (1985), "STABL5...The Spencer method of slices: Final report," Joint Highway Research Report No. JHRP-85-17, School of Civil Engineering, Purdue University, West Lafayette, Indiana 47907.

Duncan, J. M., Low, B. K., and Schaefer, V. R. (1985), "STABGM: A computer program for slope stability analysis of reinforced embankments and slopes," Department of Civil Engineering, Virginia Tech, Blacksburg, VA 24061, 28 pp.

Humphrey, D. N., and Holtz, R. D. (1986a), "Design of reinforced embankments," Joint Highway Research Report No. JHRP-86, School of Civil Engineering, Purdue University, West Lafayette, Indiana 47907.

Humphrey, D. N., and Holtz, R. D. (1986b), "Finite element analysis of plane strain problems with PS-NFAP and the cap model," Joint Highway Research Report No. JHRP-86, School of Civil Engineering, Purdue University, West Lafayette, Indiana 47907.

Ingold, T. S. (1982), "An analytical study of geotextile reinforced embankments," Proceedings of the Second International Conference on Geotextiles, Las Vegas, Nevada, August, Vol. III, pp. 683-688.

Lovell, C. W., Sharma, S. S., and Carpenter, J. R. (1984), "Slope stability analysis with STABLE4," Joint Highway Research Report No. JHRP-84-19, School of Civil Engineering, Purdue University, West Lafayette, Indiana 47907.

Siegel, R. A. (1975a), "STABL user manual," Joint Highway Research Report No. JHRP-75-9, School of Civil Engineering, Purdue University, West Lafayette, Indiana 47907.

Siegel, R. A. (1975b), "Computer analysis of general slope stability problems," Masters Thesis, School of Civil Engineering, Purdue University, West Lafayette, Indiana 47907.

APPENDIX B - EXAMPLE PROBLEM

This is a simple example on the use of the reinforcing layer option for a 6-foot high embankment with a 2h:1v side slope as shown in Fig. B-1. The embankment fill is cohesionless with a unit weight of 125 pcf and a friction angle ϕ of 30°. The foundation is soft clay with a unit weight of 115 pcf and an undrained shear strength of 125 psf. The water table is assumed to be very deep. The embankment is reinforced with a single layer located at its base. The available force is specified to be zero at the toe increasing to 500 lb/ft under the central portion of the embankment as shown in Fig. B-1. The force is assumed to act in the direction of the reinforcement so the inclination factor is 0.0. The safety factor is calculated for the trial circle shown in Fig. B-1.

The following input file was prepared using the instructions in Siegel (1975a) and Appendix C. The output for the problem is shown on the following pages. A plot of problem geometry generated using PLOTSTBL.BAS on a Hewlett-Packard 7470A plotter is also shown.

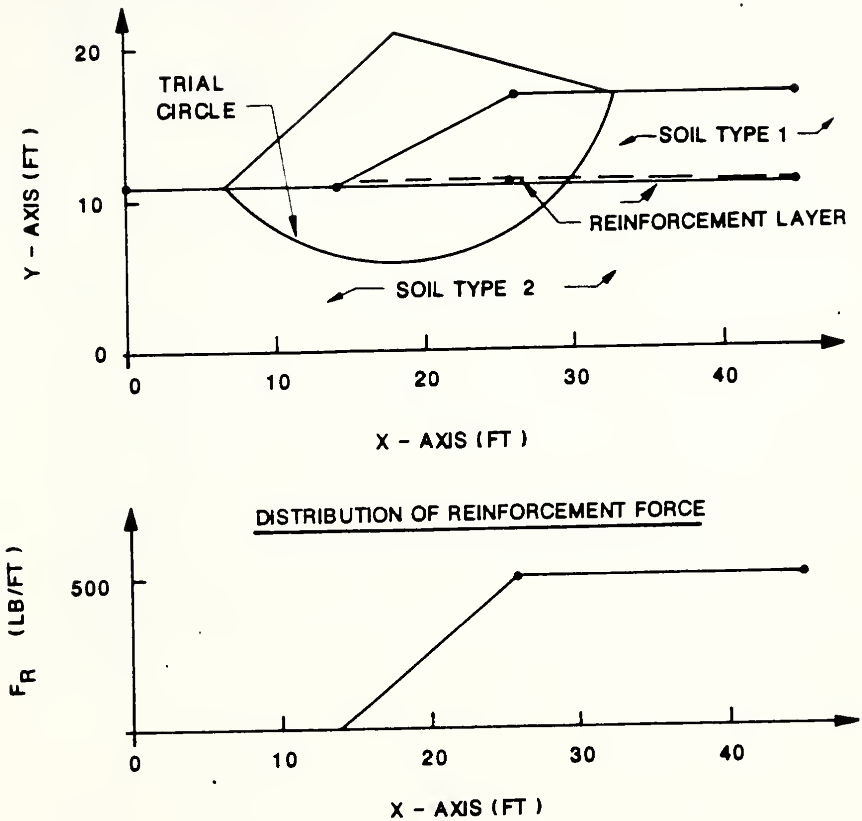


Figure B-1 Example problem.

Input for example

```
PROFIL
REINFORCED EMBANKMENT - EXAMPLE
4 3
0. 11. 14. 11. 2
14. 11. 26. 17. 1
26. 17. 45. 17. 1
14. 11. 45. 11. 2
SOIL
2
125. 125. 0. 30. 0. 0. 0
115. 115. 125. 0. 0. 0. 0
REINF
1
3
14. 11. 0. 0.
26. 11. 500. 0.
45. 11. 500. 0.
SURBIS
13
6.00 11.00
8.12 8.88
10.61 7.20
13.37 6.03
16.30 5.40
19.30 5.33
22.26 5.84
25.06 6.90
27.62 8.48
29.83 10.51
31.61 12.92
32.90 15.63
33.25 17.00
EXECUT
```

Output for example

** PCSTABL5 **

by
Purdue University

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:	6/13/86
Time of Run:	8:30 PM
Run By:	D. Humphrey
Input Data Filename:	example.in
Output Filename:	example.out
Plotted Output Filename:	example.plt

PROBLEM DESCRIPTION REINFORCED EMBANKMENT - EXAMPLE

BOUNDARY COORDINATES

3 Top Boundaries
4 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	11.00	14.00	11.00	2
2	14.00	11.00	26.00	17.00	1
3	26.00	17.00	45.00	17.00	1
4	14.00	11.00	45.00	11.00	2

ISOTROPIC SOIL PARAMETERS

2 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	125.0	125.0	0.0	30.0	0.00	0.0	0
2	115.0	115.0	125.0	0.0	0.00	0.0	0

Output for example (cont.)

REINFORCING LAYER(S)

1 REINFORCING LAYER(S) SPECIFIED

REINFORCING LAYER NO. 1

3 POINTS DEFINE THIS LAYER

POINT NO.	X-COORD	Y-COORD	FORCE	INCLINATION FACTOR
1	14.00	11.00	0.00	0.000
2	26.00	11.00	500.00	0.000
3	45.00	11.00	500.00	0.000

Trial Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	6.00	11.00
2	8.12	8.88
3	10.61	7.20
4	13.37	6.03
5	16.30	5.40
6	19.30	5.33
7	22.26	5.84
8	25.06	6.90
9	27.62	8.48
10	29.83	10.51
11	31.61	12.92
12	32.90	15.63
13	33.25	17.00

Circle Center At X = 18.1 ; Y = 21.0 and Radius, 15.7

Factor Of Safety For The Preceding Specified Surface = 1.079

WARNING - Factor Of Safety Is Calculated By The Modified Bishop Method. This Method Is Valid Only If The Failure Surface Approximates A Circle.

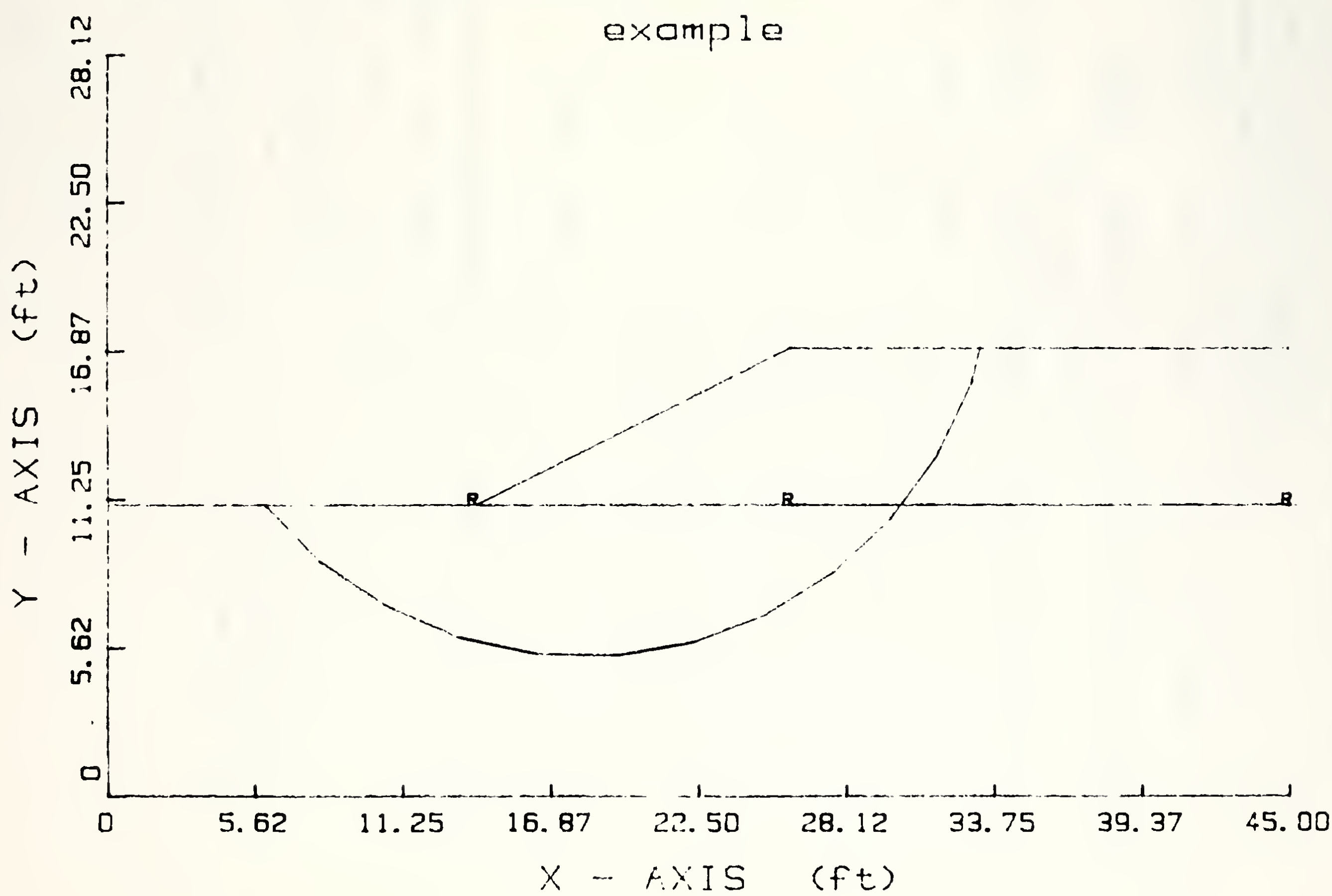
Output for example (cont.)

```
              Y            A     X     1     S            F     T

              0.00      5.63     11.25     16.88     22.50    28.13

X         0.00 +---------+---------*---------+---------+---------+
               -
               -
               -
               -
               -
          5.63 +                   S
               -
               -
               -               S
               -
               -            S
A        11.25 +
               -
               -          S        1
               -                   *
               -
               -         S
X        16.88 +
               -
               -
               -        S
               -
               -
I        22.50 +         S
               -
               -
               -           S       1
               -                   R         *
               -              S
S        28.13 +
               -
               -                  S
               -
               -                      S
               -                           S S
         33.75 +
               -
               -
               -
               -
               -
F        39.38 +
               -
               -
               -
               -
               -                   1
T        45.00 +                   *         *
```

Example plot from Hewlett-Packard 7470A plotter.



APPENDIX C - DATA INPUT FORMAT FOR REINFORCING LAYERS

C.1 Input for Reinforcing Layers

COMMAND CARD	REINF	Command Code
DATA CARD	Integer	Number of reinforcing layers

NOTE: Repeat the following set of data cards for each reinforcing layer.

DATA CARD	Integer	Number of points defining the reinforcing layer
DATA CARD	Real	X coordinate of point on reinforcing layer
	Real	Y coordinate of point on reinforcing layer
	Real	Force in reinforcement at point (force/unit width)
	Real	Inclination factor; between 0.0 and 1.0; = 0.0 force acts in plane of reinforcement; = 1.0 force acts tangent to failure surface

NOTE: Repeat preceding data card for each point defining the reinforcing layer.

C.2 Input for Suppressing of Reactivating Reinforcing Layers

COMMAND CARD	REINF	Command Code
DATA CARD	Integer	Number zero (0)

C.3 Input Restrictions

1. No more than 10 reinforcing layers can be specified.

2. A reinforcing layer must be specified by at least 2 but not more than 40 points.

3. The reinforcing force must be positive.

4. The inclination factor must be between 0.0 and 1.0. A factor of 0.0 specifies that the reinforcing force acts in the direction of the reinforcement. A factor of 1.0 specifies that the force acts tangent to the failure surface.

APPENDIX D - REINF ERROR CODES

RF01 - An attempt has been made to suppress or reactivate undefined reinforcing layers. Data must be defined by prior use of command REINF before they can be suppressed. Suppressed data can not be reactivated if command PROFIL has been used in the execution sequence subsequent to use of REINF, whether the data are active or suppressed.

RF02 - The number of reinforcing layers specified exceeds 10. The problem must either be redefined so fewer reinforcing layers are used or dimensioning of the program must be increased to accommodate the problem as defined.

RF03 - The number of points defining a reinforcing layer exceeds 40. The problem must be either redefined so fewer points are used or the dimensioning of the program must be increased to accommodate the problem as defined.

RF04 - A negative coordinate has been specified for the reinforcing layer and point number indicated. All problem geometry must be located within the first quadrant.

RF05 - A negative reinforcing force has been specified for the reinforcing layer and point number indicated. The reinforcing force must be zero or positive.

RF06 - An inadmissible inclination factor has been specified for the reinforcing layer and point number indicated. The inclination factor must be between 0.0 and 1.0.

RF07 - The reinforcing layer and point number indicated is not to the right of the points specified prior to it. The points defining the reinforcing layer must be specified in left to right order.

RF08 - The reinforcing layer indicated is specified by only one point. The reinforcing layer must be specified by at least two points.

RF09 - An attempt has been made to use the reinforcing layer option with the simplified Janbu method of analysis. The reinforcing layer option can only be used with the simplified Bishop method of analysis.

APPENDIX E - MODIFICATIONS TO PC-STABL5

This appendix describes modifications made to PC-STABL5 which was originally compatible with Microsoft FORTRAN, Version 3.21 (MS-FORTRAN). The modifications were made for two reasons. The first were changes to make the program compatible with Ryan-McFarland, Version 2.00 FORTRAN (RM-FORTRAN). These were mostly minor such as commas in format statements and are listed below. In addition, MS-FORTRAN uses a special $NOFLOATCALLS statement at the beginning of each program unit; these were made inactive in the RM-FORTRAN version by substituting CNOFLOATCALLS. The MS-FORTRAN version writes program output simultaneously to a file (unit 6) and to the screen (unit *). This was done with two WRITE statements, one for each unit. This scheme is not compatible with RM-FORTRAN since it treats unit 6 and unit * as the same unit. To eliminate the problem all WRITE statements to unit * were made inactive by inserting `c **' in columns 1-4. The second reason for the changes was to incorporate the reinforcing layer option. The modifications are listed below. They included minor modifications to several existing subroutines and the addition of two new subroutines.

<u>Modifications to main program STABL5</u>

```
Add after stbl  12
c   1986 Modifications for reinforcing layer option (PCSTABL6)          dnhmay86
c                                                                       dnhmay86
c        Dana N. Humphrey, Graduate Research Assistant, May 1986.       dnhmay86
c                                                                       dnhmay86
Add after stbl 160
      common /blk23/ireinf,nreinf,nrpts(10),xreinf(10,40),              dnhmay86
     ^              yreinf(10,40),rforce(10,40),rinclf(10,40),rmoms     dnhmay86
Add after stbl 168
      real load,limit,kcoef,inclin,length                               dnhmay86
      integer sltp,bn                                                   dnhmay86
Replace existing jrcmay85 following stbl 172 with
     1     'LIMITS','ANISO','SURBIS','SPENCR','REINF'/                  dnhmay86
Add after stbl 200
      ireinf=0                                                          dnhmay86
      rmoms=0.                                                          dnhmay86
Replace existing jrcmay85 following stbl 324 with
   23 do 12 i=1,18                                                      dnhmay86
Replace existing jrcmay85 following stbl 328 with
     1    13,30,35),i                                                   dnhmay86
Replace existing jrcmay85 following stbl 350 with
c *** write(*,102)(keyw(i),i=1,18)                                      dnhmay86
      write(6,102)(keyw(i),i=1,18)                                      dnhmay86
Add after stbl 510
   35 call reinf                                                        dnhmay86
      go to 11                                                          dnhmay86
```

<u>Modifications to subroutine BLOCK2</u>

```
Add after blk2  56
      real limit                                                        dnhmay86
```

<u>Modifications to subroutine EXECUT</u>

```
Add before exec 46
      common /blk23/ireinf,nreinf,nrpts(10),xreinf(10,40),              dnhmay86
     ^              yreinf(10,40),rforce(10,40),rinclf(10,40),rmoms     dnhmay86
Add after exec 62
      if(ireinf.eq.1)call reinf2                                        dnhmay86
```

<u>Modifications to subroutine FACTR</u>

```
Add after fctr 148
      common /blk23/ireinf,nreinf,nrpts(10),xreinf(10,40),              dnhmay86
     ^              yreinf(10,40),rforce(10,40),rinclf(10,40),rmoms     dnhmay86
Recpace existing fctr 296 with
      do 10 j=1,20                                                      dnhjul86
```

```
Replace existing fctr 314 with
      if(ireinf.eq.1)then                                          dnhmay86
      bottom=sumb-rmoms/(radius*fold)                              dnhjul86
      if(bottom.gt.0.)then                                         dnhjul86
      fnew= sumt/bottom                                            dnhjul86
      fnew=(fold+fnew)/2.                                          dnhjul86
      else                                                         dnhjul86
      fnew=2.*fold                                                 dnhjul86
      endif                                                        dnhjul86
      else                                                         dnhmay86
      fnew= sumt/sumb                                              dnhmay86
      endif                                                        dnhmay86
Add after fctr 322
      foldx=fold                                                   dnhjul86
Replace existing fctr 338 with
     110x,'Factor Of Safety Calculation Has Gone Through 20 Iterations' dnhjul86
Replace existing fctr 346 and 348 with
      if(isearc.eq.0) write(6,108)fs,foldx                         dnhjul86
c *** if(isearc.eq.0) write(*,108)fs,foldx                         dnhjul86
  108 format(//10x,'Factor of Safety for the Preceding Surface is ', dnhjul86
     1       'Between',f6.3,' and',f6.3)                           dnhjul86
Replace existing fctr 374 and 376 with
      write(6,108)fs,foldx                                         dnhjul86
c *** write(*,108)fs,foldx                                         dnhjul86
Add before fctr 386
      rmoms=0.                                                     dnhmay86
Replace existing fctr 414 with
     110x,'***  The Above Factor Of Safety Is Misleading  ***')    dnhmay86
Replace existing fctr 430 through 438 with
     110x,'The Factor Of Safety For The Trial Failure Surface Defined'/ dnhmay86
     110x,'By The Coordinates Listed Below Is Misleading.'///      dnhmay86
     110x,'Failure Surface Defined By',i3,' Coordinate Points'///  dnhmay86
     112x,'Point',6x,'X-Surf',6x,'Y-Surf',/                        dnhmay86
     113x,'No.',8x,'(ft)',8x,'(ft)',//)                            dnhmay86
```

<u>Modifications to subroutine FSPENC</u>

```
Replace existing fspn 726 with
     110x,'***  The Above Factor Of Safety Is Misleading  ***')    dnhmay86
Replace existing fspn 742 through fspn 750 with
     110x,'The Factor Of Safety For The Trial Failure Surface Defined'/ dnhmay86
     110x,'By The Coordinates Listed Below Is Misleading.'///      dnhmay86
     110x,'Failure Surface Defined By',i3,' Coordinate Points'///  dnhmay86
     112x,'Point',6x,'X-Surf',6x,'Y-Surf',/                        dnhmay86
     113x,'No.',8x,'(ft)',8x,'(ft)',//)                            dnhmay86
Replace existing fspn 780 and fspn 782 with
  201 write(6,202)                                                 dnhmay86
c *** write(*,202)                                                 dnhmay86
```

Modifications to subroutine PLOTIN

```
Add after plot 62
      common /blk23/ireinf,nreinf,nrpts(10),xreinf(10,40),            dnhmay86
     ^               yreinf(10,40),rforce(10,40),rinclf(10,40),rmoms  dnhmay86
Replace existing plot  66 with
      dimension plttr(11)                                             dnhmay86
Replace existing plot  76 with
     1      'SRF','TEN','RNF','NPL','END'/                            dnhmay86
Replace existing plot 96 with
      write(7,100)plttr(10)                                           dnhmay86
Add after plot 376
c ----------------------------------------                            dnhmay86
c   plot reinforcing layers, if applicable                            dnhmay86
c ----------------------------------------                            dnhmay86
    3 if(ireinf.eq.0)go to 49                                         dnhmay86
      write(7,100)plttr(9)                                            dnhmay86
      write(7,113)nreinf                                              dnhmay86
      do 45 n=1,nreinf                                                dnhmay86
      write(7,113)nrpts(n)                                            dnhmay86
      x=xreinf(n,1)/scle                                              dnhmay86
      y=yreinf(n,1)/scle                                              dnhmay86
      write(7,115)x,y                                                 dnhmay86
      nn=nrpts(n)                                                     dnhmay86
      do 45 i=2,nn                                                    dnhmay86
      x=xreinf(n,i)/scle                                              dnhmay86
      y=yreinf(n,i)/scle                                              dnhmay86
      write(7,115)x,y                                                 dnhmay86
   45 continue                                                        dnhmay86
Replace existing plot 384 with
   49 if(iblk.eq.0)go to 9                                            dnhmay86
```

Modifications to subroutine PLTN

```
Add after pltn  62
      common /blk23/ireinf,nreinf,nrpts(10),xreinf(10,40),            dnhmay86
     ^               yreinf(10,40),rforce(10,40),rinclf(10,40),rmoms  dnhmay86
Replace existing pltn  64 with
      dimension plt(49,51),symb(21),axis(9),scl(9)                    dnhmay86
Add after pltn  66
      real load,inclin,length                                         dnhmay86
      integer bn                                                      dnhmay86
Add after pltn  68
      character plt*1                                                 dnhmay86
Replace existing pltn  72 with
     1    'W','L','S','.','/','T','R'/                                dnhmay86
Add after pltn 366
c ------------------------------------------------------------        dnhmay86
c   position points defining reinforcing layers, if applicable        dnhmay86
c ------------------------------------------------------------        dnhmay86
   10 if(ireinf.eq.0)go to 39                                         dnhmay86
      do 36 i=1,nreinf                                                dnhmay86
      nn = nrpts(i)                                                   dnhmay86
```

```
      do 36 j=1,nn                                        dnhmay86
      call postn(xreinf(i,j),yreinf(i,j),ix,iy)           dnhmay86
      plt(ix-1,iy)=symb(i)                                dnhmay86
      plt(ix,iy)=symb(21)                                 dnhmay86
   36 continue                                            dnhmay86
Replace existing pltn 374 with
   39 do 8 i=1,nbnd                                       dnhmay86
```

Modifications to subroutine PROFIL

```
Add after prof 98
      real load,limit,inclin,bn,length                    dnhmay86
Replace existing prof 150 with
     1        29x,'Purdue University')                    dnhmay86
Replace existing prof 172 with
     1        10x,'Output Filename:          ',a)         dnhmay86
Replace existing prof 176 with
  201 format(10x,'Plotted Output Filename:  ',a)          dnhmay86
```

Modifications to subroutine RANDOM

```
Replace existing rand 620 with
     110x,'Sliding Block is',f6.1,//)                     dnhmay86
```

Modifications to subroutine READER

```
Add after read  46
      character m*1                                       dnhmay86
```

Modifications to subroutine SCALER

```
Add after scal  64
      real load,inclin,length                             dnhmay86
      integer bn                                          dnhmay86
```

Modifications to subroutine SLICES

```
Add before slic  50
      real load                                           dnhmay86
```

Modifications to subroutine SOILWT

```
Add after slwt 40
      integer sltp                                        dnhmay86
```

Modifications to subroutine TIES

Replace existing ties 222 with

```
  105 format(/,10x,14h****  ERROR - ,a4,6h  ****,5x,4hTie ,i3,/)        dnhmay86
```

Modifications to subroutine TRANS

Add after tran 68

```
      integer sitp                                                       dnhmay86
```

Modifications to subroutine WEIGHT

Relplace existing lines wght 200 through wght 208 with

```
     110x,'*******************************************************'/      dnhmay86
     110x,'******  INPUT ERROR - Trial Failure Surface   ******'/         dnhmay86
     110x,'******                Extends Above The       ******'/         dnhmay86
     110x,'******                Ground Surface          ******'/         dnhmay86
     110x,'*******************************************************'/)     dnhmay86
```

New subroutine REINF

```
      SUBROUTINE REINF
C   ------------------------------------------------------------------
C   ------------------------------------------------------------------
C                        SUBROUTINE REINF
C   ------------------------------------------------------------------
C   ------------------------------------------------------------------
C
C   FUNCTIONS -
C
C       READ THE NUMBER OF REINFORCING LAYERS.
C
C       IF EQUAL TO ZERO, EXISTING REINFORCING LAYER DATA IS SUPPRESSED
C       OR RECACTIVATED IF PREVIOUSLY SUPPRESSED.
C
C       IF GREATER THAN ZERO, READS, CHECKS, STORES, AND PRINTS
C       REINFORCING LAYER DATA.
C
C    -----------------------------------------------------------------
C    -----------------------------------------------------------------
C
CNOFLOATCALLS
      COMMON /BLK01/IANGL,IBLK,IEXIT,ICIRC,ILIMIT,IPLOT,IREAD,ISEARC,
     1             IBLK2,ISOIL,ISTR,ISURC,ISURF,ITIES,IWAT,RD,TOL,
     1             CBLK,CPLT
      COMMON /BLK23/IREINF,NREINF,NRPTS(10),XREINF(10,40),
     ^             YREINF(10,40),RFORCE(10,40),RINCLF(10,40),RMOMS
      DIMENSION ERROR(8)
      CHARACTER ERROR*4
      DATA ERROR/'RF01','RF02','RF03','RF04','RF05','RF06','RF07',
     ^           'RF08'/
```

```
C    ---------------------------------
C    READ NUMBER OF REINFORCING LAYERS
C    ---------------------------------
       CALL READER(DUMMY,NREIN,0)
C    ---------------------------------------------
C    CHECK FOR REINFORCING LAYER DATA SUPPRESSION
C    ---------------------------------------------
       IF(NREIN.EQ.0) THEN
         IF(IREINF.NE.0) THEN
           IREINF=0
C ***      WRITE(*,108)
           WRITE(6,108)
  108      FORMAT(///,
     ^      10X,'REINFORCING LAYER DATA LAYER DATA HAS BEEN SUPPRESSED')
C    --------------------------------------------
C    CHECK IF DATA DEFINED BEFORE REACTIVATING IT
C    --------------------------------------------
         ELSE IF(NREINF.EQ.0) THEN
C ***      WRITE(*,101)ERROR(1)
           WRITE(6,101)ERROR(1)
  101      FORMAT(/,10X,14H****  ERROR - ,A4,6H  ****,/)
           IEXIT=1
C    -------------------------
C    REACTIVATE SUPPRESSED DATA
C    -------------------------
         ELSE
           IREINF=1
C ***      WRITE(*,109)
           WRITE(6,109)
  109      FORMAT(///,
     ^      10X,'SUPPRESSED REINFORCING LAYER DATA HAS BEEN REACTIVATED')
         ENDIF
         RETURN
       ENDIF
       NREINF=NREIN
       IREINF=1
C    ---------------------------------
C    PRINT NUMBER OF REINFORCING LAYERS
C    ---------------------------------
C *** WRITE(*,103)NREINF
      WRITE(6,103)NREINF
  103 FORMAT(1H1,
     ^   ///,9X,'REINFORCING LAYER(S)',//,
     ^   13X,I2,' REINFORCING LAYER(S) SPECIFIED')
C    -------------------------------------
C    CHECK REINFORCING LAYER STORAGE LIMIT
C    -------------------------------------
      IF(NREINF.GT.10)THEN
C ***   WRITE(*,101)ERROR(2)
        WRITE(6,101)ERROR(2)
        CALL QUIT
      ENDIF
      DO 20 I=1,NREINF
C    -------------------------------------
```

```
C   READ NUMBER OF POINTS DEFINING LAYER
C   ------------------------------------
         CALL READER(DUMMY,NRPTS(I),0)
C   ----------------------------
C   CHECK FOR AT LEAST TWO POINTS
C   ----------------------------
         IF(NRPTS(I).LT.2)THEN
C ***      WRITE(*,101)ERROR(8)
           WRITE(6,101)ERROR(8)
           IEXIT=1
         ENDIF
C   ------------------------
C   CHECK POINT STORAGE LIMIT
C   ------------------------
         IF(NRPTS(I).GT.40)THEN
C ***      WRITE(*,101)ERROR(3)
           WRITE(6,101)ERROR(3)
           CALL QUIT
         ENDIF
C   -------------------------------------
C   PRINT REINFORCING LAYER DATA HEADINGS
C   -------------------------------------
C ***    WRITE(*,102) I,NRPTS(I)
         WRITE(6,102) I,NRPTS(I)
  102    FORMAT(///,
     ^    10X,'REINFORCING LAYER NO. ',I3//
     ^    10X,I3,' POINTS DEFINE THIS LAYER',//
     ^    15X,'POINT',5X,'X-COORD',3X,'Y-COORD',3X,'FORCE',3X,
     ^    'INCLINATION'/
     ^    16X,'NO.',36X,'FACTOR'/)
C   -------------------------------------
C   READ AND CHECK REINFORCING LAYER DATA
C   -------------------------------------
         XP=-TOL
         YP=-TOL
         DO 10 N=1,NRPTS(I)
           CALL READER(XREINF(I,N),IDUMMY,1)
           CALL READER(YREINF(I,N),IDUMMY,1)
           CALL READER(RFORCE(I,N),IDUMMY,1)
           CALL READER(RINCLF(I,N),IDUMMY,1)
C   ------------------------------
C   CHECK FOR 1ST QUADRANT LOCATION
C   ------------------------------
           IF(XREINF(I,N).LE.-TOL .OR. YREINF(I,N).LE.-TOL)THEN
C ***        WRITE(*,104)ERROR(4),I,N
             WRITE(6,104)ERROR(4),I,N
  104        FORMAT(/,10X,14H****  ERROR - ,A4,6H  ****,5X,
     ^        'LAYER NO.',I3,5X,'POINT NO.',I3)
             IEXIT=1
           ENDIF
C   -----------------------------------
C   CHECK FOR POSITIVE REINFORCING FORCE
C   -----------------------------------
           IF(RFORCE(I,N).LE.-TOL)THEN
```

```
C ***        WRITE(*,104)ERROR(5),I,N
             WRITE(6,104)ERROR(5),I,N
             IEXIT=1
           ENDIF
C   ----------------------------------
C   CHECK LIMITS OF INCLINATION FACTOR
C   ----------------------------------
           IF(RINCLF(I,N).LE.-TOL .OR. RINCLF(I,N).GT.1.+TOL)THEN
C ***        WRITE(*,104)ERROR(6),I,N
             WRITE(6,104)ERROR(6),I,N
             IEXIT=1
           ENDIF
C   --------------------------
C   CHECK FOR POSITIVE SPACING
C   --------------------------
           IF(XREINF(I,N).LT.XP .OR. YREINF(I,N).LT.YP)THEN
C ***        WRITE(*,104)ERROR(7),I,N
             WRITE(6,104)ERROR(7),I,N
             IEXIT=1
           ENDIF
           XP=XREINF(I,N)
           YP=YREINF(I,N)
   10   CONTINUE
C   ----------------------------
C   PRINT REINFORCING LAYER DATA
C   ----------------------------
C ***   WRITE(*,106) (N,XREINF(I,N),YREINF(I,N),RFORCE(I,N),RINCLF(I,N),
C ***^    N=1,NRPTS(I))
        WRITE(6,106) (N,XREINF(I,N),YREINF(I,N),RFORCE(I,N),RINCLF(I,N),
     ^    N=1,NRPTS(I))
  106   FORMAT(15X,I3,3X,3F10.2,F10.3)
   20 CONTINUE
      RETURN
      END
```

<u>New subroutine REINF2</u>

```
      SUBROUTINE REINF2
C   ------------------------------------------------------------------
C   ------------------------------------------------------------------
C                       SUBROUTINE REINF2
C   ------------------------------------------------------------------
C   ------------------------------------------------------------------
C
C   FUNCTIONS -
C
C       LOCATES INTERSECTION BETWEEN TRIAL SURFACE AND REINFORCING
C       LAYER(S).
C
C       CALCULATES RESISTING MOMENT PROVIDED BY REINFORCING LAYER(S).
C
C   ------------------------------------------------------------------
C   ------------------------------------------------------------------
```

```
C
CNOFLOATCALLS
      COMMON /BLK01/IANGL,IBLK,IEXIT,ICIRC,ILIMIT,IPLOT,IREAD,ISEARC,
     1             IBLK2,ISOIL,ISTR,ISURC,ISURF,ITIES,IWAT,RD,TOL,
     1             CBLK,CPLT
      COMMON /BLK05/NSURF,SURF(100,2)
      COMMON /BLK15/M,MB
      COMMON /BLK22/RADIUS
      COMMON /BLK23/IREINF,NREINF,NRPTS(10),XREINF(10,40),
     ^             YREINF(10,40),RFORCE(10,40),RINCLF(10,40),RMOMS
      DIMENSION ERROR(1)
      CHARACTER ERROR*4
      DATA ERROR/'RF09'/
C   -------------------------------------------
C   CHECK THAT MODIFIED BISHOPS METHOD SPECIFIED
C   -------------------------------------------
      IF(MB.NE.1)THEN
C ***   WRITE(*,101)ERROR(1)
        WRITE(6,101)ERROR(1)
  101   FORMAT(/,10X,14H****  ERROR - ,A4,6H  ****,/)
        CALL QUIT
      ENDIF
      RMOMS=0.
C   --------------------------------------------
C   CHECK FOR INTERSECTION AND CALCULATE RESISTING
C   MOMENT FOR EACH REINFORCING LAYER
C   --------------------------------------------
      DO 30 I=1,NREINF
C   -------------------------------------------------------------
C   LOCATE INTERSECTION BETWEEN TRIAL SURFACE AND REINFORCING LAYER
C   -------------------------------------------------------------
        NRPTSI=NRPTS(I)
        DO 10 J=NRPTSI,2,-1
          J1=J-1
          DO 10 K=NSURF,2,-1
            K1=K-1
            CALL INTSCT(XREINF(I,J1),YREINF(I,J1),XREINF(I,J),
     ^        YREINF(I,J),SURF(K1,1),SURF(K1,2),SURF(K,1),SURF(K,2),
     ^        XINT,YINT,INTS)
            IF(INTS.EQ.1) GOTO 20
   10   CONTINUE
C   --------------------------------------------
C   IF NO INTERSECTION GO TO NEXT REINFORCING LAYER
C   --------------------------------------------
        GOTO 30
C   ------------------------------------------------------------------
C   INTERPOLATE REINFORCING FORCE AND INCLINATION FACTOR AT INTERSECTION
C   ------------------------------------------------------------------
   20   FAC=(XREINF(I,J1)-XINT)/(XREINF(I,J1)-XREINF(I,J))
        RFORCI=RFORCE(I,J1)+FAC*(RFORCE(I,J)-RFORCE(I,J1))
        RINCLI=RINCLF(I,J1)+FAC*(RINCLF(I,J)-RINCLF(I,J1))
C   ------------------------------------------------
C   FOR FORCE TANGENT TO CIRCLE MOMENT ARM EQUALS RADIUS
C   ------------------------------------------------
```

```
          IF(RINCLI.GE.1.-TOL)THEN
            RARM=RADIUS
          ELSE
C   --------------------------
C   CALCULATE CENTER OF CIRCLE
C   --------------------------
            X1=SURF(1,1)
            Y1=SURF(1,2)
            X2=SURF(2,1)
            Y2=SURF(2,2)
            X3=SURF(3,1)
            Y3=SURF(3,2)
            XHALF2=(X2 + X3)/2.0
            YHALF2=(Y2 + Y3)/2.0
            XCNTR=((X1**2-X2**2)*(Y3-Y2) - (X2**2-X3**2)*(Y2-Y1) + (Y3-Y1)
     1             *(Y2-Y1)*(Y3-Y2))/(2.0*((X1-X2)*(Y3-Y2) - (X2-X3)*
     2             (Y2-Y1)))
            YCNTR=(X2-X3)/(Y3-Y2)*(XCNTR - XHALF2) + YHALF2
C   -----------------------------------------------------
C   CALCULATE MOMENT ARM FOR FORCE NOT TANGENT TO CIRCLE
C   -----------------------------------------------------
            A1=ATAN((YREINF(I,J)-YREINF(I,J1))/(XREINF(I,J)-XREINF(I,J1)))
            A2=ATAN((XINT-XCNTR)/(YCNTR-YINT))
            A3=A1+RINCLI*(A2-A1)
            A4=1.570796327-A2+A3
            RARM=RADIUS*SIN(A4)
          ENDIF
C   ---------------------------------
C   CALCULATE AND SUM RESISTING MOMENT
C   ---------------------------------
          RMOM=RFORCI*RARM
          RMOMS=RMOMS+RMOM
   30 CONTINUE
      RETURN
      END
```

APPENDIX F - LIST OF ADDITIONS AND MODIFICATIONS TO PLOTSTBL.BAS

The modifications which were made to PLOTSTBL.BAS to give it the capability to plot the location of reinforcing layers are listed below. An 'A' in the first column indicates that the line should be added to the existing program and 'R' indicates that the line should replace the existing line.

<u>Modifications to PLOTSTBL.BAS</u>

```
R 530 DIM PLT$(11)
R 730 FOR I=1 TO 11
R 1090 FOR J=1 TO 11
R 1110 ON J GOTO 1140,1360,1570,1750,1940,2152,2310,2450,2131,2600,2700
A 2131 REM ---------------------------------------
A 2132 REM   PLOT REINFORCING LAYERS, IF APPLICABLE
A 2133 REM ---------------------------------------
A 2134 IF PROMPT$="y" THEN GOSUB 2900
A 2135 INPUT #2,NREINF%
A 2136 FOR I=1 TO NREINF%
A 2137 INPUT #2,NN%
A 2138 GOSUB 2830
A 2139 PRINT #1, "PU,PA";X#,Y#;
R 2140 PRINT #1, "SI.15,.2"
A 2141 PRINT #1, "CP-.5,0;DI;LBR"+CHR$(3)
A 2142 PRINT #1, "PU,PA";X#,Y#;
A 2143 FOR J=2 TO NN%
A 2144 GOSUB 2830
A 2145 GOSUB 2770
A 2146 PRINT #1, "CP-.5,0;DI;LBR"+CHR$(3)
A 2147 PRINT #1, "PU,PA";X#,Y#;
A 2148 NEXT J
A 2149 NEXT I
R 2150 GOSUB 2770
A 2151 GOTO 1130
A 2152 REM ---------------------------------------------
A 2153 REM   PLOT SEARCH BOXES FOR BLOCK, IF APPLICABLE
R 2950 FOR JJ=1 TO 9
R 2970 ON J GOSUB 3000,3030,3060,3090,3120,3150,3180,3210,3241
A 3241 INPUT "SELECT PEN FOR PLOTTING REINFORCING LAYERS (1 OR 2) ";XX
A 3242 GOSUB 3250
A 3243 RETURN
A 3401 DATA RNF
```

COVER DESIGN BY ALDO GIORGINI